

Optimization of Power Delivery System Using Smart Grid Technology to Meet the Challenges of the 21st Century

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Abstract: A Smart Grid comprises of a broad range of technology solutions that optimize the energy value chain. Depending on where and how a specific utility operates across that chain, it can benefit from deploying certain parts of a Smart Grid solution set. This paper presents opportunities for utilities and consumers to benefit from efficient management of energy, advanced equipment and devices which will wisely improve the nation's energy system. Those regulatory barriers and other challenges to a Smart Grid are discussed. Optimization of the deployment schedule will enhance many benefits of Smart Grid Technology: Improvements to the power delivery system, Enabling defensive strategies to detect and address problems before they become widespread grid disturbances, Enabling widespread Integration of alternative energy sources and providing a means for mitigating their intermittency, Greatly expanding the connection of end-user loads to grid information and control to facilitate energy efficiency improvements, Providing the necessary information and control to integrate plug-in hybrid electric vehicles into the grid to meet the challenges of the 21st century.

Keywords: Electric power, energy, optimization, reliability and Smart Grid.

I. INTRODUCTION

An electric power system has two infrastructures: An electric infrastructure that carries the electric energy in the power system, and an information infrastructure that monitors, controls and performs other functions related to the electric infrastructure. The existing electric power grid has long been designed to withstand numerous problems, including equipment breaks, thunderstorms, System operators rely on the intelligence that comes from electromechanical automation -- Intelligent Electronic Devices (IEDs) -- sophisticated control centres that enable operators to view the state of the system second by second, and perform on-line studies that anticipate grid malfunctions effects. Redundant communications and computer systems are used to operate the grid, such that control is passed seamlessly from one to another when a computer fails. These functions have been part of the electric grid system.

However, computer and communications technology advances at a much more rapid pace than is prudent for upgrading power grid field equipment. As a result, the technology in the grid tends to lag, sometimes by decades. The older technology tends to be relatively inflexible, and upgrades to satisfy new requirements tend to be disruptive. Newer computer and communications technology has developed standards that provide greatly enhanced flexibility and enable new requirements to be supported and improved capabilities introduced with minimal disruption.

The Smart Grid encompasses the information and control functionality that will monitor, control, manage, coordinate, integrate, facilitate, and enable achievement of many innovation benefits envisioned for national energy

policy. The principal focus of the Smart Grid effort is to identify the requirements of the new information infrastructure, and to define a body of compatible (interoperable) standards to be used in its implementation

A Smart Grid uses digital technology to improve reliability, security, and efficiency of the electric system: from large generation, through the delivery systems to electricity consumers and a growing number of distributed generation and storage resources [1]. The information networks that are transforming our economy in other areas are also being applied to applications for dynamic optimization of electric system operations, maintenance, and planning. Resources and services that were separately managed are now being integrated and rebundled as we address traditional problems in new ways, adapt the system to tackle new challenges, and discover new benefits that have transformational potential [1].

According to the Galvin Electricity Initiative and the Electric Power Research Institute (EPRI), the economic and environmental benefits of transforming the current electric power delivery system into a Smart Grid are numerous. A Smart Grid brings the power of networked, interactive technologies into an electricity system, giving utilities and consumer's unprecedented control over energy use, improving power grid operations, and ultimately reducing costs to consumers. Table 1 summarizes the value of a Smart Grid deployment for the various stakeholders.

The EPRI *Electricity Sector Framework for the Future* estimates \$1.8 trillion in annual additive revenue by 2020 with a substantially more efficient and reliable grid. [2]

To elaborate, according to the Galvin Electricity Initiative, "Smart Grid technologies would reduce power disturbance costs and also reduce the need for massive infrastructure investments [3].

In addition, efficient technologies can dramatically reduce total fuel consumption—and thereby potentially reduce fuel prices for all consumers. Virtually the nation's entire economy depends on reliable energy. The availability of high-quality power could help determine the future of the Nigeria economy. See Table 2 for an outline of the value of an enhanced electric power system. Additionally, a Smart Grid creates new markets as private industry develops energy-efficient and intelligent appliances, smart meters, new sensing and communications capabilities, and passenger vehicles.

Around the globe, countries are pursuing or considering pursuit of greenhouse gas legislation suggesting that public awareness of issues stemming from greenhouse gases has never before been at such a high level. According to the National Renewable Energy Laboratory [4], "utilities are pressured on many fronts to adopt business practices that respond to global environmental concerns. Smart Grid technologies could reduce carbon emissions by [2] :

- Leveraging demand response / load management to minimize the use of costly peaking generation, which typically uses generation that is comparatively fuel inefficient
- Facilitating increased energy efficiency through consumer education, programs leveraging usage information, and time-variable pricing
- Facilitating mitigation of renewable generation variability of output—mitigation of this variability is one of the chief obstacles to integration of large amounts of renewable energy capacity into the bulk power system.
- Integrating plug-in hybrid electric vehicles (PHEVs), distributed wind and photovoltaic solar energy resources, and other forms of distributed generation

2.0 BENEFITS TO UTILITIES

2.1 Reduced Operations and Maintenance Costs

Smart Grid technologies allow for remote and automated disconnections and reconnections, which eliminate unneeded field trips, reduce consumer outage and high-bill calls, and ultimately reduce operations and maintenance (O&M) costs. Reduced costs can also result from near real-time remote asset monitoring, enabling utilities to move from time based maintenance practices to equipment-condition based maintenance. Using enhanced information about grid assets from Smart Grid monitoring technologies, grid operators can reduce the risk of overloading problematic equipment—especially transmission power transformers. Simply keeping the transformers in service risks increased failure rates and even greater outage costs, as well as larger disruptions or more severe damage to system equipment. However, doing so is often a necessity, as the cost of replacing transformers has increased rapidly, along with the prices for copper and ferromagnetic steel. Today, multi-function sensors are available that can continuously monitor a number of physical parameters for signs of incipient failure (e.g., insulation breakdown,

loosening of fasteners that hold windings in place). Information from these devices, together with sophisticated analysis of fault conditions from power circuit breakers that protect the transformers, can help determine when the equipment needs maintenance, repairs, and eventually replacement.

2.2 Increased Efficiency of Power Delivery

Up to a 30% reduction in distribution losses is possible from optimal power factor performance and system balancing [5].

Today, this problem is managed to some extent by controlled or automated capacitor banks on distribution circuits and in substations. Control of these devices can be greatly improved with better real-time information. Almost all higher efficiency appliances, heating, ventilation, and cooling (HVAC) systems, consumer electronics, lighting, and other load devices are changing from being “resistive” (e.g., incandescent light bulbs) or “rotating” (as in motors) to “inverter based.” The transition of load from “resistive” to “inverter based” means that the overall system performance, especially with respect to power factor and reactive power needs, changes dramatically over time. Smart Grid technologies offer utilities increased monitoring of rapid power changes and help them adapt control schemes and deploy capacitors and other power factor control devices—including power electronics based devices in substations—to compensate.

2.3 Integration of Renewable Energy and Distributed Resources

Smart Grid technologies will allow the grid to better adapt to the dynamics of renewable energy and distributed generation, helping utilities and consumers more easily access these resources and reap the benefits. Today’s grid was designed to move power from centralized supply sources to fixed, predictable loads; this makes it challenging for the grid to accept input from many distributed energy resources across the grid. And because resources such as solar and wind power are intermittent, the grid will require integrated monitoring and control, as well as integration with substation automation, to control differing energy flows and plan for standby capacity to supplement intermittent generation. Smart Grid capabilities will make it easier to control bidirectional power flows and monitor, control, and support these distributed resources.

2.4 Improved System Security

Utilities are increasingly employing digital devices in substations to improve protection, enable substation automation, and increase reliability and control. However, these remotely accessible and programmable devices can introduce cyber security concerns. Smart Grid technology and capabilities will offer better integration of these devices, increased use of sensors, and added layers of control. Smart Grid technologies, however, can bring their own cyber security concerns, which will require comprehensive, built-in security during implementation. Smart Grid technologies can do the following:

- Bring higher levels of investment and greater penetration of information technology (IT) into the grid, allowing utilities to address cyber security issues more effectively.
- Increase the robustness of the grid to withstand component failures, whether due to natural events, age/condition of assets, or hostile causes.
- Allow grid components and IT systems in time to detect intrusion attempts and provide real-time notification to cyber security organizations.

3.0 CHALLENGES AND OPPORTUNITIES

The biggest impediment to the smart electric grid transition is neither technical nor economic,[6]. Instead, the transition is limited today by obsolete regulatory barriers and disincentives that echo from an earlier era [6]. Those regulatory barriers and other challenges to a Smart Grid are discussed in detail below.

3.1 Regulatory Challenges

The nation’s electric power delivery system is much like the telecommunications network of the past—dated and increasingly costly for consumers. Three decades ago, one phone company was the monopoly provider of services across much of the United States, and it was illegal to plug other companies’ telephones and devices into that company’s network. Today, telecommunications choices and services are much greater thanks to legislation and

technological advances that broke up the monopoly and later opened the door to competition in the telecommunications industry. The Energy Independence and Security Act of 2007, with its support for Smart Grid research and investment, is an important step forward in achieving .Similar results for the power industry, although more government involvement is needed to remove obstacles to further innovation.[3]

State Public Utility Commissions (PUCs) are responsible for ensuring that electric utilities under their jurisdiction provide safe and reliable service at a reasonable price. PUCs analyze and determine if proposed utility infrastructure investments, like the deployment of Smart Grid technologies, are prudent investments. Investments are often evaluated based upon actual and realizable benefits, and while future benefits may be considered, they must be evaluated appropriately. The state-by-state PUC approval process could create a patchwork approach, as different Smart Grid improvements could be adopted by neighbouring states or even utilities within one state. PUCs also need to develop unique rate structures using Smart Grid technology by creating special time-of-use rates, whether hourly, critical peak pricing, or some other modification from the existing approaches. As technology advances and as the nation approaches the building of a Smart Grid, consumers and utilities will have a greater opportunity to control their electric consumption in response to price and system conditions.

3.2 Lack of a Coordinated Strategy

The efficient evolution to a Smart Grid will require a coordinated strategy that relies upon building an appropriate electric infrastructure foundation to maximize utilization of the existing system. A Smart Grid is a new integrated operational and conceptual model for utility operations. Among other things, it envisions the real-time monitoring of all utility transformers, transmission and distribution line segments, generation units, and consumer usage, along with the ability to change the performance of each monitored device. This will require significant planning for both implementing a system-wide installation of monitoring devices (including monitoring devices at the consumer level), and for installing the equipment necessary to enable parts of the system to “talk” with other components and take rerouting, self-healing, and other actions independent of system operators. Developing such an integrated system requires a multi-year, phased installation of Smart Grid devices and upgraded computer and communication capabilities; those investing in this technology likely will not realize the value until the return value of the combined benefits of these technologies are achieved.

3.3 Cost

As discussed, the effort to move from using smarter technology to a Smart Grid is a significant undertaking that needs focused coordination both strategically and tactically. This undertaking also will require significant investment. Investors often face the challenges of access to capital to make these investments, as well as the lack of ability to bear the associated costs of the expenses. Utilities must grapple with making Smart Grid investments, knowing that significant utility and consumer benefits may not occur for several years. A Smart Grid is a complex, comprehensive, and integrated monitoring and operating system; it will provide publicly observable benefits only after considerable investments have been made in upgrading the infrastructure of the nation’s utilities and the monitoring and control devices in the homes and businesses of consumers. Investing in equipment and personnel training, for which there are few short-term benefits, creates operating costs that may be difficult to justify without policy direction and support from government agencies.

3.4 Key Infrastructure Issues

Without question, creating a Smart Grid presents many complex technical challenges. Chief among them are the integration issues associated with the automation systems that manage the nation’s transmission and distribution networks, along with the interface codes and standards required to enable a more reliable and smoothly operating electric system. One of the most important foundations of a Smart Grid is the interoperability that enables all of the required devices, technologies, and agents (for example, energy producers, consumers, and operators) to interact beneficially in the network. Interoperability has been defined as the ability of two or more systems or components to exchange information and to use the information that has been exchanged [7]. In the case of a Smart Grid, these

systems might include outage management, distribution management, condition-based maintenance, supervisory control and data acquisition (SCADA), advanced metering infrastructure (AMI), distribution planning, load forecasting, and a variety of systems that have not been designed or built yet. Ultimately, when a new device is added to the system, interoperability will enable it to register itself in the grid upon installation, communicate its capabilities to neighbouring systems, and cause the connectivity database and control algorithms to update themselves automatically. Evidence from other industries indicates that interoperability generates tangible cost savings and intangible benefits amounting to 0.3%–4% in cost savings or avoided construction. [8] A Smart Grid will require interoperability among the many technology components involved. New solutions must also be configured to exchange information with legacy systems, including existing back office systems and other systems that need to be connected. The past 20 years have seen tremendous progress in collaborative efforts across the industry to address issues associated with interoperability, assist utilities and integrators in achieving interoperability. Industry support for continued development in several areas could significantly improve the potential state of interoperability, thereby improving the cost-benefit ratio of deploying a Smart Grid [9].

3.5 Security

The vision of a Smart Grid typically boasts enhanced system security. The report of [10] goes on to list the following design features and functions:

- Identification of threats and vulnerabilities
- Protecting the network
- Inclusion of security risk in system planning

Expected benefits include:

- ✓ Reduced system vulnerability to physical or cyber attack
- ✓ Minimal consequences of any disruption, including its extent, duration, or economic impact
- ✓ Using security-related improvements to also help optimize reliability, communications, computing, decision-making support and self-healing

However, many of the technologies being deployed to support Smart Grid projects—such as smart meters, sensors, and advanced communications networks—can themselves increase the vulnerability of the grid to cyber attacks. Accordingly, it is essential that Smart Grid deployment leverage the benefits of increased threat awareness while mitigating against heightened security concerns. It will be a difficult task, but one that can be addressed by being aware of the risks and leveraging security best practices from other industries.

4.0 CONCLUSION

A Smart Grid presents opportunities for utilities and consumers to benefit from efficient management of energy and advanced equipment and devices. It offers significant opportunities to wisely manage the nation's fuel resources by potentially reducing the national need for additional generation sources, better integrating renewable and non-renewable generation sources into the grid's operations, reducing outages and cascading problems, and enabling consumers to better manage their energy consumption. DOE has the opportunity to address many of these challenges and accelerate the deployment schedule so that the nation can achieve the many benefits a Smart Grid offers.

RECOMMENDATIONS

Considering the importance of a Smart Grid, it can be a mechanism for achieving the nation's goals in the areas of energy security, climate change, grid reliability, economic growth, and national competitiveness. At the same time, there are serious challenges to the timely development of a Smart Grid. The following are recommended:

1. Create a Smart Grid Program office within Department of Energy DOE.

This office should do the following:

- Act as a clearinghouse of global Smart Grid information via web-based self-service tools.
- Provide information on, at a minimum, worldwide best practices, effective Smart Grid business models, available technologies, and effective regulatory models.
- Develop and make available educational materials to utility regulators, utilities, consumer advocates, and other stakeholders.

- Provide or support coordination of Smart Grid activities among diverse organizations, if appropriate.
 - Drive standards-based work once the National Institute of Standards and Technology (NIST) completes its development of a framework.
2. Conduct a focused education campaign. This DOE campaign should focus on educating consumers on the cost of energy and how those costs can be better managed.
 3. Establish a Smart Grid engineer and technician development program that encourages students to pursue Smart Grid-related technical degrees.
 - Define appropriate university training for these new generation engineers leveraging the existing land-grant universities in every state for assistance in disseminating information.
 - Create a workforce training program to ensure that working technicians have the skills needed to work with Smart Grid technologies.
 4. Work with industry, state regulators, and other stakeholders to create incentives and standards that will drive a market for Smart Grid ready controllable devices beyond the meter.

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Table 1. Smart Grid Benefits Matrix**Potential and Real benefits to be realized by building and implementing a smart Grid**

Benefit	Stakeholder					
	Utility	Independent Generator	Residential	Commercial	Industrial	Future Generations
System Reliability and Economics						
Smart Grid technologies allow faster diagnosis of distribution outages and automated restoration of undamaged portions of the grid, reducing overall outage times with major economic benefits.	X		X	X	X	
Smart Grid's automated diagnostic and self-healing capability prolongs the life of the electric infrastructure.	X					X
Distributed generation is supported because the grid has the ability to dynamically manage all sources of power on the grid.	X	X	X	X	X	X
Price-sensitive peak shaving defers the need for grid expansion and retrofit.	X					
Price-sensitive peak shaving reduces the need for peaking generation capacity investments.	X		X	X	X	
Smart Grid technologies may allow better utilization of transmission paths, improving long distance energy transfers.	X	X				
Positive Environmental Impact						
Smart Grid can reduce distribution losses, thus reducing power generation demands.	X		X	X	X	X
Grid integration of high levels of renewable resources as called for in many state RPS standards will require Smart Grid to manage extensive distributed generation and storage resources	X	X	X	X	X	X
A high penetration of PHEV will require Smart Grid to manage grid support of vehicle charging. Potential use of PHEV as Vehicle to Grid will absolutely require Smart Grid technologies.	X		X			
A Smart Grid enables intelligent appliances to provide feedback through the system, sense grid stress, and reduce their power use during peak demand periods.	X		X			
Advanced metering technology can be used to help measure electricity use and calculate the resulting carbon footprint.			X	X	X	X
Increased efficiency of power delivery						
Direct operating costs are reduced through the use of advanced metering technology (AMR/AMI) such as connects/disconnects, vehicle fleet operations and maintenance, meter reads, employee insurance compensation insurance, etc	X					
Smart Grid technologies, such as synchrophasors, offer the promise of reducing transmission congestion.	X	X	X	X	X	
Economic Development						
Standards and protocols supporting interoperability will promote product innovation and business	X	X	X	X	X	X

opportunities that support the Smart Grid concept.						
Consumer Choice						
Provide consumers with information on their electric usage so they can make smart energy choices.			X	X	X	X
Real-time pricing offers consumers a "choice" of cost and convenience trade-offs that are superior to hierarchical demand management programs.			X	X	X	
Integration of building automation systems offers efficiency gains, grid expansion deferral, and peak shaving.	X			X		

Source: Table created for *Smart Grid: Enabler of the New Energy Economy* by EAC Smart Grid Subcommittee 2008

Table 2 Value of an Enhanced Electric Power System

2000		2025		
Parameter	Baseline	Business as Usual (BAU)	Enhanced Electric Power System	Improvement of Enhanced Productivity Over BAU
Electricity Consumption (billion kilowatt hours kwh]	3,800	5800	4900-5200	10% – 15% reduction
Delivered Electricity Intensity (kwh/\$GDP)	0.41	0.28	0.2	29% reduction
% Demand Reduction at Peak	6%	15%	25%	66% increase
% Load Requiring Digital Quality Power	<10%	30%	50%	66% increase
Carbon Dioxide Emissions (million metric tons of carbon)	590	900	720	20% reduction
Productivity Growth Rate (%/year)	2.9	2.5	3.2	28% increase
Real GDP (billions of dollars, 1996)	9,200	20700	24300	17% increase
Cost of Power Disturbances to Businesses (billions of dollars, 1996)	100	200	20	90% reduction

Source: Electric Power Research Institute 2003. [Electric Power Research Institute, *Electricity Sector Framework for the Future Volume I: Achieving the 21st Century Transformation* (Washington, DC: Electric Power Research Institute, 2003).]